Reply on RC2

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Author comment on "Quantifying the role of moss in terrestrial ecosystem carbon dynamics in northern high latitudes" by Junrong Zha and Qianlai Zhuang, Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-57-AC2, 2021

General comments

This study addresses a critical gap in the Terrestrial Ecosystem Model by including mosses as a plant type at northern latitudes (>45 degrees). The authors do a good job of establishing the key role of moss in these ecosystems and show an improvement in model-data assimilation from the previous iteration of the model through the inclusion of mosses. In general, this is an important contribution to improving these models. However, some non-trivial caveats may have large effects on the future carbon storage potential of high latitude ecosystems, particularly the expected decreases in moss biomass with climate warming.

Specific comments:

- Throughout the manuscript, I would suggest replacing "higher plants" with a more appropriate terminology, such as "vascular plants". For a discussion on why (and how) to implement this change, please see McDaniel 2021 in New Phytologist (Title: Bryophytes are not early diverging land plants)

Response: Thanks for the suggestions and comments. In this revision, we replaced all "higher plants" with "vascular plants".

- In order to support the claim that this paper quantifies the interaction between vascular plants and mosses as mentioned in the abstract and introduction, I would like to see a more explicit explanation of how that interaction was included within the model.

Response: Thanks for the comments. In TEM_Moss, we have explicitly considered moss effects on soil thermal dynamics, soil water and soil moisture, and nutrient conditions in boreal ecosystems. Mosses compete with vascular plants for water and nutrient (nitrogen) in the modeling system. Three kinds of effects are described below:

- Moss effects on soil thermal dynamics: In TEM 5.0, a moss plus fibric soil organic layer is considered and specified with respect to thickness through site-level

parameterization. Here moss layer thickness was explicitly considered for each pixel.

- Moss effects on water balance: In TEM 5.0, water balance is modeled as the difference between precipitation, vascular plant evapotranspiration, runoff, and percolation. In TEM_Moss, water loss through moss is considered, and soil water content is thus affected by both vascular plants and mosses.   See equations 17 and 18 in the text.
- Nutrient feedbacks, in TEM 5.0, N balance is modeled without considering moss N uptake. The change rate of soil organic N is modeled as the difference between the vascular plant N uptake and net N mineralization rate. In TEM_Moss, N uptake is modeled as:

$Nuptake = Nuptake_v + Nuptakem$ (16)

Thus, the change rate of soil organic N is affected and the N feedbacks to C cycling is affected by considering moss N uptake.

- In the discussion, the authors say their simulation confirms that that mosses and vascular plants respond similarly to climate change in terms of productivity. He et al. 2016 (Title: Will bryophytes survive in a warming world?) finds an expected divergence between vascular plants and bryophytes in response to climate change, as do many experimental manipulations (see below). It seems like the authors set up the model to have vascular plants and mosses respond similarly, rather than the model proving that they do? It may also be worth considering the higher CO2 concentration at the moss carpet—is it appropriate to use mean atmospheric CO2 concentration?

Response: Thanks for the comments. While there were a number of studies suggesting that the bryophyte act differently from vascular plants in terms of photosynthesis, nutrient uptake, and carbon allocation, and fundamental plant physiology, the algorithms of these processes of moss are not ready to be implemented in modeling activities. Here we made a number of assumptions in our Method section to model moss productivity and nutrient uptake. To further address your concerns, we added a few sentences to discuss this limitation in Discussion section. Regarding your comments on moss responses to climate change, we added "Future moss dynamics will also impact carbon dynamics in this region. For instance, a long-term warming experiments along natural climatic gradients, ranging from Swedish subarctic birch forest and subarctic/subalpine tundra to Alaskan arctic tussock tundra concluded that both diversity and abundance of mosses are likely to decrease under arctic climate warming (Long et al. 2012). Similarly, total moss cover declined in both heath and mesic meadow under experimental long-term warming (by 1.5–3 °C), driven by general declines in many species (Alatalo et al., 2020).   Due to global warming, significant losses in moss diversity are expected in boreal forests and alpine biomes, leading to changes in ecosystem structure and function, nutrient cycling, and carbon balance (He et al., 2015)."

Additionally, we have to acknowledge that our modeling can not reveal moss physiology and associated carbon cycling processes, rather we strive to incorporate the knowledges into modeling to quantify carbon consequences. It is still difficult to quantify the level of CO2 concentration near /inside of mosses clusters so as to have more accurate quantification of CO2 impacts on moss productivity.

- I think the potentially large decreases in moss biomass expected with warming are a non-trivial concern for future carbon storage expectations found in this model. I would recommend papers such as Elmendorf et al. 2012, Lang et al. 2012, and Alatalo et al. 2020 as sources on changes in moss biomass in response to simulated warming.

Response: Thanks for the comments. We cited these references to discuss the potential changes of moss diversity and abundance and their effects on ecosystem structure and functioning and carbon dynamics. "Future moss dynamics will also impact carbon dynamics in this region. For instance, a long-term warming experiments along natural climatic gradients, ranging from Swedish subarctic birch forest and subarctic/subalpine tundra to Alaskan arctic tussock tundra concluded that both diversity and abundance of mosses are likely to decrease under arctic climate warming (Long et al. 2012). Similarly, total moss cover declined in both heath and mesic meadow under experimental long-term warming (by 1.5–3 °C), driven by general declines in many species (Alatalo et al., 2020). Due to global warming, significant losses in moss diversity are expected in boreal forests and alpine biomes, leading to changes in ecosystem structure and function, nutrient cycling, and carbon balance (He et al., 2015)."

- Soil uptake is only one pathway for mosses to access N. Studies have shown that they receive nitrogen from associations with nitrogen fixers (see Bay et al 2013 and Berg et al 2013 for examples in various types of host mosses). Mosses can translocate N from within the senescent moss body to incorporate new growth (Aldous 2002). Mosses also acquire nitrogen via deposition. The cited studies (Ayres et al. 2006 and Fritz et al. 2014) show that mosses can acquire nitrogen from soil (a previously unexpected N source due to the lack of roots and vasculature), but in Ayres et al. mosses incorporated more nitrogen via wet deposition.

Response: We recognize the limitation of current understanding of N uptake and its algorithms in our current modeling. While these N uptake pathways are potentially important to moss productivity, the data and knowledges are not sufficient to allow us represent these processes in the model. In this revision, we cited these studies to discuss future efforts to improve moss N uptake representations in modeling. We added this following to Discussion "First, due to the limited understanding of moss photosynthesis (He et al., 2015) and various moss N uptake pathways (e.g., Bay et al 2013; Berg et al 2013), a few important assumptions have been made in our modeling. For instance, we assume that mosses behave similarly to vascular plants regarding photosynthesis and soil N uptake is the only pathway for mosses without considering N uptake through N fixers and atmospheric wet N deposition (Ayres et al. 2006)."

Technical corrections

L22 ""which do not" instead of "without" moss.

Response: Changed.

L27 "nutrient" should be nutrients.

Response: Changed.

L41 "hold" instead of occupy, perhaps?

Response: Changed.

L59 Rephrase for clarity

Response: Rephrased the sentence as "However, the role of boreal forests in carbon sink or source activities has not been clear due to a number of model limitations".

L69 "nutrient" should be nutrients.

Response: Changed.

L81 Since the degree to which mosses facilitate nitrogen fixation is not well-studied across the broad array of host mosses, rephrase to say "because of their associations with microbial nitrogen fixers" or similar.

Response: Changed.

L83 "of" not "on"

Response: Changed.

L84 "being" recognized.

Response: Changed.

L90 "exceeding" instead of "exceed".

Response: Changed.

L98 "higher plants" <- but also, see comment above.

Response: Changed.

L103 Rephrase—perhaps exclude interaction?

Response: Excluded the word "interaction".

L210: This sounds like a great feature of the model!

Response: Thanks.

L307-308 Very cool result. I think this is a major take-away of this study.

Response: Thanks.

L403 Please refer to a table or figure here to direct audience to that finding.

Response: We did not compare modeled NPP with observations, thus we deleted "Thus, with incorporation of moss into our models, NPP estimation in our model is improved." in this revision.

L422-424 Past tense for past estimates?

Response: Changed.

L458 "which have their own functional traits" I would like to see a couple key traits enumerated—perhaps differing levels of insulation provided for soil, perhaps different associated microbiomes? Whichever may be most relevant to the assumptions within the model. Also remove next sentence that starts "In our model,…".

Response: We revised the sentence to "Different kinds of mosses may provide different levels of insulation for soil, resulting in different soil thermal conditions that affect microbial activities.".

Figure 1: Since Moss as a category was added in this model, perhaps the Moss boxes should also be green? I would find that helpful in interpreting the figure.

Response: Changed the color of Moss boxes to green.

Figure 3: Include a map as an inset or separate figure to show the location of these sites. I was surprised to see that half were on the southern end of area included in TEM_Moss, would you expect this to impact your results in any way?

Response: Added a map to show the sites for calibration. The locations for sites won't influence the calibration results.

Follow-up question: Why was 45 degrees N selected as the cut-off point? This includes temperate, boreal, and Arctic ecosystems--though the introduction and discussion seem tailored more to the Arctic and boreal ecosystems.

Response: For model comparison convenience, we generally treat 45 ºN above region as pan arctic.

Please also note the supplement to this comment:
https://bg.copernicus.org/preprints/bg-2021-57/bg-2021-57-AC2-supplement.pdf